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A RADIO RESOURCE SCHEDULING ALGORITHM FOR A SECTORIZED CELLULAR CO-OPERATIVE NETWORK

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ABSTRACT

This paper investigates radio resource scheduling for a sectorized cellular co-operative network. A method based on a scheduling matrix is proposed and implemented to get the optimal solution for resource block scheduling in a cellular network and the resulting optimal cases show three types of transmission: full cooperation, non-cooperation and 2/3 reuse. According to the results of the optimal solution, a low-complex location-based algorithm which aims to maximize the total network bandwidth efficiency is then proposed. The results from the proposed algorithm show that it can achieve nearly 99% of the optimal bandwidth efficiency whilst reducing the complexity significantly.

I. INTRODUCTION

Due to the rapid development of the mobile electronic device market and the high demands of the consumers, high data rate, high spectrum efficiency and reliable Quality of Service (QoS) are required for the wireless communication systems. With limited available spectrum, efficient use of resources to get a high QoS for the users is a key problem. Resource allocation problems have been investigated with regards to several aspects such as jointly user scheduling and power allocation, channel allocation and fairness of both single cell environments and multi-cell environments [1]-[12]. But the optimal solution of resource block scheduling to maximize the total network bandwidth efficiency including cooperative transmission in cellular networks had been seldom addressed. This paper investigates the scheduling of resource blocks to get as much total network bandwidth efficiency as possible including the possibility of cooperative transmission between cells. There are several previous works on the optimal solution of jointly resource scheduling and power control [1][2][6]. Although some algorithms have been published on some specific settings such as symmetric network of interfering links and a 2-cell network, the general optimal solution is considered to be very complex to obtain due to that the SINR expression remains non-convexity [1][2][6][12]. Binary power allocation is

optimal only for the network of no more than 2 cells [1]. In this paper, a method based on a scheduling matrix to obtain the optimal solution of resource scheduling problem for any cellular network is proposed. Moreover, according to the user distributions of all the resulting optimal cases for the investigated network, a location-based algorithm is proposed and it uses two steps to select an optimal resource scheduling case. This low-complex algorithm also can get a total bandwidth efficiency which is nearly the same as the optimal result.

The rest of this paper is organized as follows: network layout and related equations used are presented in section II. The proposed method for getting the optimal solution is explained in section III. The details of the proposed location-based algorithm are given in section IV. The simulation results from the algorithms are presented and discussed in section V. Section VI concludes this paper.

II. SYSTEM MODEL

II.1 Network layout

The investigated network consists of N adjacent cells. A Base Station (BS) is assumed to be located at the center of each cell, and U users in total are randomly placed within these N cells. Moreover, in total M orthogonal resource blocks are available for scheduling in this network. Frequency reuse is flexible and any one resource block may be scheduled in any of the N cells for transmission to any user. Data may be transmitted cooperatively from multiple base stations to one user on one resource block (cooperative transmission) or independent data may be transmitted from multiple base stations to multiple users on a non-cooperative basis (multiple access). Resource block is assumed to be the smallest resource unit that can be scheduled and the power of each resource block is assumed to be the same.

II.2 Problem statement

The simulation parameters for a typical LTE urban macro environment defined by 3GPP are listed in table 1 [14]. The SINR of user u on the m^{th} resource block is

Table 1: Simulation parameters

Parameter	Value
Network layout	Hexagonal 3 cells
Cell radius	500m
Antenna	Omnidirectional
Carrier Frequency	2GHz
Bandwidth	10MHz
Distance-dependent path loss	$128.1+37.6*\log_{10}(d)$ d in km
Thermal noise power spectral density	-174dBm/Hz
Maximum BS transmit power	40watts
Mobile station noise figure	9dB
Minimum distance between user and BS	35m

$$S'_{u,m} = \frac{\sum_{n \in \Omega_n} P_{u,n}}{N_s + \sum_{n' \in \Omega_{n'}} P_{u,n'}}, \quad \Omega_n, \Omega_{n'} \subseteq [1, N] \quad (1)$$

where $P_{u,n} = P_m / P_{L,u,n}$ (P_m is transmit power on the m^{th} RB; $P_{L,u,n}$ is the path loss from user u to the n^{th} BS) represents the received power of the user u from the n^{th} BS. Ω_n is the set of base stations that use the m^{th} RB to transmit signals to the user u (cooperative transmission occurs if there are more than one BS in this set) while $\Omega_{n'}$ stands for the set of the base stations that also use the m^{th} RB but to transmit to the other users in the network. The base stations in Ω_n and $\Omega_{n'}$ are from 1 to N , and no elements may overlap between Ω_n and $\Omega_{n'}$. N_s is the noise power. (1) shows the SINR expression for the case that the m^{th} RB is scheduled for the transmission between the base stations in the set of Ω_n to the user u , whilst the m^{th} RB is also used by the base stations in the set of $\Omega_{n'}$ but to transmit to the other users in the network as the interference to the user u .

The capacity of user u on the m^{th} resource block is

$$C_{m,u} = B_m \log_2(1 + S'_{m,u}), \quad (2)$$

where B_m is the bandwidth of the m^{th} resource block.

Then, the total bandwidth efficiency ρ_{total} is

$$\rho_{\text{total}} = \frac{1}{B_{\text{total}}} \sum_{m=1}^M \sum_{u=1}^U C_{m,u}, \quad (3)$$

where B_{total} is the total bandwidth used for the scheduling. The aim of this paper is to get the optimal total bandwidth efficiency of the network by scheduling resource blocks, so the objective function is

$$\max_{n,m,u} \frac{1}{B_{\text{total}}} \sum_{m=1}^M \sum_{u=1}^U C_{m,u}. \quad (4)$$

III. OPTIMAL SOLUTION: EXHAUSTIVE SEARCH

Exhaustive search is a common method of finding the optimal result [4][13]. Since the optimal solution of the resource allocation problem is considered to be very difficult to solve, a method based upon exhaustive search is proposed. The proposed algorithm uses a matrix to display the allocation details of the scheduled resources in a cellular network, and then total bandwidth efficiency for the network is calculated according to the matrix. The optimal solution is displayed as the matrix corresponding to the maximal total bandwidth efficiency. This proposed algorithm contains the search of the cases using flexible frequency reuse and cooperative transmission between cells.

III.1 Scheduling matrix

In an N cell layout, M resource blocks are going to be scheduled for the transmission of signals from N base stations to U users. The scheduling matrix is shown in table 2.

The value of u_{nm} is the index of which user receives a signal and its range is from 0 to U : 0 means no user, 1 means user₁, etc. u_{nm} is used to represent the case that resource block m is scheduled for the transmission from the n^{th} base station to the user u_{nm} , e.g., if u_{23} is 2, u_{23} indicates that resource block 3 is scheduled for the transmission from the 2nd base station to user₂. The values of u_{nm} in the matrix vary with different combinations of scheduled resource blocks. The number of all combinations for the network layout is $(U+1)^{NM}$.

III.2 SINR equation of the scheduling matrix

The key equation relating to the scheduling matrix is the expression of SINR of any user u receiving a signal on any resource block m (the m^{th} column), which is modified from (1) to

$$S'_{m,u} = \frac{\sum_{n=1}^N (k_{nm} P_{n,u})}{N_s + \sum_{n=1}^N (k_{nmv} P_{n,u})}, \quad (1.1)$$

with respect to the following conditions:

$$\begin{cases} k_{nm} = 0 \text{ and } k_{nmv} = 0, & \text{if } u_{nm} = 0; \\ k_{nm} = 1 \text{ and } k_{nmv} = 0, & \text{if } u_{nm} = u; \\ k_{nm} = 0 \text{ and } k_{nmv} = 1, & \text{if } u_{nm} \neq u \text{ and } u_{nm} \neq 0. \end{cases} \quad (1.2)$$

In (1.1), $P_{n,u}$ is the received power from the n^{th} base station to user u . k_{nm} and k_{nmv} are binary indices for allocating $P_{n,u}$ to signal or interference according to

Table 2: Matrix of scheduling M resource blocks (RB) among N base stations (BS) and U users

BS \ RB	M	.....	2	1
N	u_{NM}	.....	u_{N2}	u_{N1}
.	.	u_{nm}	.	.
2	u_{2M}	.....	u_{22}	u_{21}
1	u_{1M}	.....	u_{12}	u_{11}

the value of u_{nm} in the matrix of table 2. (1.1) replaces (1) in section II-2.

The scheduling problem can be solved by the matrix corresponding to the maximal total bandwidth efficiency:

$$\arg \max_{u_{nm}} \rho_{\text{total}} . \quad (5)$$

III.3 Optimal cases

This proposed method can be applied to different settings. In this paper, the optimal scheduling is obtained for a 3-cell layout with one base station in the centre of each cell and one user randomly located within each cell. The number of available resource blocks is 3. According to table 2, the scheduling case is expressed as 9 digits: $u_{33}u_{32}u_{31}u_{23}u_{22}u_{21}u_{13}u_{12}u_{11}$. Thus, there are 4^9 possible combinations for the search of optimum in a 3-cell layout network with 3 users in total and 3 resource blocks in total. However, inspection of the results from the optimum shows that 7 of these 4^9 cases are the optimal candidates in the network considered. The 7 optimal cases can be further categorized into 3 types where user₁ (1) is located within cell₁, user₂ (2) is located within cell₂ and user₃ (3) is located within cell₃:

1. Full cooperation case: 111111111, 222222222 and 333333333

2. 2/3 reuse non-cooperative case: 000222111, 333000111 and 333222000

3. Full frequency reuse non-cooperative case: 333222111

The full cooperation case means that all the base stations in the network use all the resource blocks to transmit a signal to the same user. The 2/3 reuse non-cooperative case means that one of the base stations in the network does not transmit on the resource blocks in order to reduce interference to the users in the other two cells. The full frequency reuse non-cooperative case means that all the users in the network are served by a base station using all the resource blocks and also they get interference from all the other base stations in the network.

IV. LOCATION-BASED ALGORITHM

Since the optimal solution based on the exhaustive search takes enormous time consumption to get the results as the number of users and number of resource blocks increase, a low-complex sub-optimal algorithm aiming to get as much total bandwidth efficiency as possible is proposed. The proposed algorithm can be implemented in a 3-cell layout with M resource blocks in total and U users in total (at least one user in each cell). Since the sub-optimal algorithm aims to maximize the total bandwidth efficiency, it is highly possible that the user with the best channel condition in each cell gets all the resources (Greedy scheduling). Firstly, the user with the highest SINR value for each cell is selected as the candidates for the scheduling process. In the SINR value, the received power from the user's own base station is the signal and the received powers from the other base stations are the interference. Then, according to the user distributions of the three optimal types, which will be displayed in section V, the proposed algorithm uses two steps to select an optimal case: SINR Comparison (SC) and Location Check (LC). Location check (LC) is to check which sector the user is located at and to compare the user's distance from its own base station (BS) with a constraint value. The algorithm selects an optimal case as the following conditions for each of the three types:

1. For full cooperation, SC and LC conditions are:

SC1: sinr_u is the largest of all SINR values.

LC1: the distances from the users (except user_u) to their own base stations are:

i. larger than c_{r1} when they are at the sector (120°) adjacent to the other cells;

ii. larger than c_{r2} when they are at the other two sectors (240°).

If the conditions both SC1 and LC1-i are satisfied or both SC1 and LC1-ii are satisfied, the case that full cooperation transmission to user_u is selected.

2. For 2/3 reuse non-cooperative case, SC and LC conditions are:

SC2: sinr_u is the smallest of all SINR values.

LC2: the distance from user_u to its own base station is larger than c_r if user_u is at the sector (120°) adjacent to the other cells.

If the conditions both SC2 and LC2 are satisfied, the case that user_u's own BS not transmitting on the M resource blocks is selected.

3. Otherwise, full frequency reuse non-cooperative case is selected.

sinr_u represents the SINR of the user_u. c_{r1} , c_{r2} and c_r are constraint values used to compare with the distance from a user to its own base station. According to the user distribution figures of the optimal cases which will

be illustrated in section V, c_{r1} is smaller than c_{r2} . Moreover, the values of c_{r1} , c_{r2} and c_r will also be discussed in section V.

V. SIMULATION RESULTS

The investigated network is a 3-cell layout with one user in each cell and three resource blocks in total. User₁ is in the left cell (as cell₁), user₂ is in the upper right cell (as cell₂) and user₃ is in the lower right cell as (cell₃). The resource blocks are scheduled according to the three algorithms: the optimal solution (based on the exhaustive search), full frequency reuse non-cooperation (the 333222111 case, also a special case of Round-robin scheduling) and the proposed location-based algorithm. Results are obtained for an ensemble of 1000 independent user location drops.

V.1 Optimal cases

Table 3 displays the 7 candidates of optimal cases and the corresponding percentage of time which it is optimal. From this table, the 333222111 case is selected the most times as the optimal case. This is why the proposed low-complex algorithm treats this case as a default.

Figure 1 illustrates the distribution of the user locations when the 000222111 case is optimal. From the distribution, the users in cell₁ and cell₂ are randomly located within their own cells but far apart from each other, while the users in cell₃ are very far away from their own base station and mainly located at the edge of the sector area which is adjacent to cell₁ and cell₂. Therefore, the channel conditions of the users in cell₃ are worse than those of the users in cell₁ and cell₂, and this is the main reason why the base station in cell₃ is prevented from transmitting. Additionally, most of the users in cell₃ are placed at a distance of 0.6-0.7 times the cell radius. Therefore, the value of c_r in the low-complex algorithm is set at this range. Equivalent

Table 3: Optimal cases

Case index	Percentage (%)
000222111	8.0
333000111	7.6
333222000	7.9
111111111	5.8
222222222	7.0
333333333	5.8
333222111	57.9

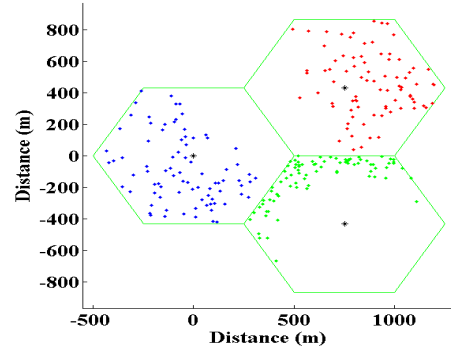


Figure 1: User distribution of optimal case 000222111

conclusions can be drawn for the 333000111 case and the 333222000 case.

Figure 2 illustrates the distribution of the user locations when the 111111111 case is optimal. The distribution shows that the users in cell₂ and cell₃ are far away from their own base stations: most of them are located at the edges of the sector area which is adjacent to the other two cells, the rest of the users are located around the other four edges of their own cells; while the users in cell₁ are around their own base station and also near the edges of cell₂ and cell₃. Since the channel conditions of the users in cell₁ are better than those of the users in cell₂ and cell₃, and also the users in cell₁ are not far from the base stations in cell₂ and cell₃, the optimal case is chosen as 3-cell full cooperation transmission to the users in cell₁. Additionally, most of the users in cell₂ and cell₃ are placed at a distance of 0.5-0.6 times the cell radius and the rest of them are placed at a distance of 0.8-0.9 times the cell radius. Therefore, the value of c_{r1} in the low-complex algorithm can be set at the range of 0.5-0.6 times the cell radius, and the value of c_{r2} in the low-complex algorithm can be set at the range of 0.8-0.9 times the cell radius. Again, equivalent conclusions can be drawn for the 222222222 case and the 333333333 case.

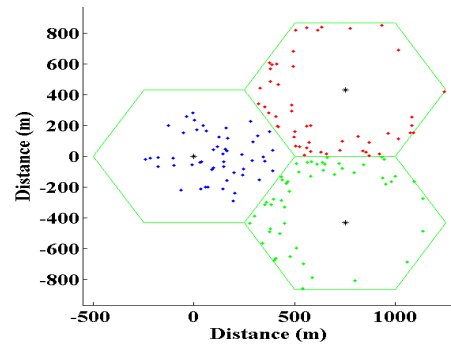


Figure 2: User distribution of optimal case 111111111

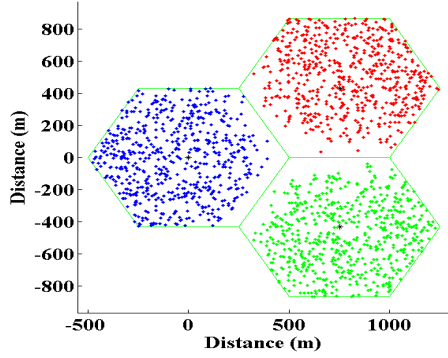


Figure 3: User distribution of optimal case 333222111

Figure 3 illustrates the distribution of the user locations when the 333222111 case is optimal. The distribution of the users in the network are randomly placed within each of their own cells but are far away from each other, so there is no obvious distribution regularity to set as a condition for this case, again, motivating that it be treated as the default case in the low-complex algorithm.

V.2 Algorithm results

The total bandwidth efficiencies of the optimal solution, non-cooperation transmission and the location-based algorithm are compared in figure 4. From figure 4, although the non-cooperation transmission is selected the most times as the optimal case, it performs worse than the proposed location-based algorithm. The two curves of the optimal solution and location-based algorithm are nearly the same above 13bps/Hz while also close to each other below 13bps/Hz. This indicates that the performance of the location-based algorithm is quite good but underperforms the optimum slightly at lower efficiencies. Moreover, the simulation results show that the percentage of the optimal cases correctly selected by the location-based algorithm is 75.2% and

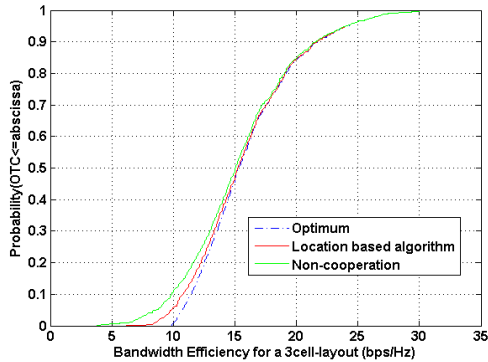


Figure 4: Comparison of the network bandwidth efficiency

the total network bandwidth efficiency obtained by the location-based algorithm is 98.49% of that of the optimum. Although the percentage of correctly selected cases is not very good, the bandwidth efficiency accuracy is nearly 99%, which is consistent with the CDF plot in figure 4 and suggests that when sub-optimum allocations are chosen, they result in only small losses of bandwidth efficiency.

Table 4 compares the complexity of the two proposed algorithms in the N-cell layout with in total U users and in total M resource blocks. For the simulated case, the complexity of the optimal solution is $O(4^9 \rho_{com} + (4^9 - 1)n)$ and complexity of the location-based algorithm is $O(3n^2 + 16n + \rho_{com})$, where ρ_{com} is the complexity of (3). The optimal solution needs to calculate total bandwidth efficiency 4^9 times while the location-based algorithm only needs to do so once. Therefore, the location-based algorithm reduces the

Table 4: Complexity equations of two algorithms

Optimum	Algorithm
$O((U+1)^{NM} \rho_{com} + [(U+1)^{NM} - 1]n)$	$O(Un^2 + (UN + 3N - 2)n + \rho_{com})$

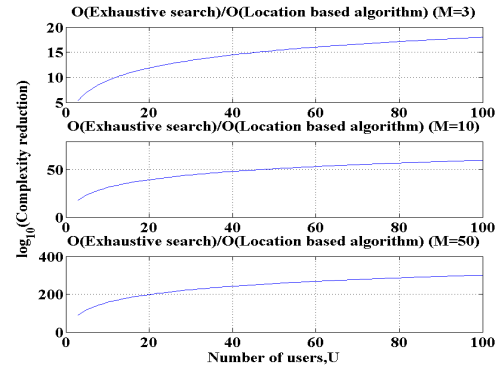


Figure 5-a: Complexity reduction with N=3 and M=3, 10 and 50

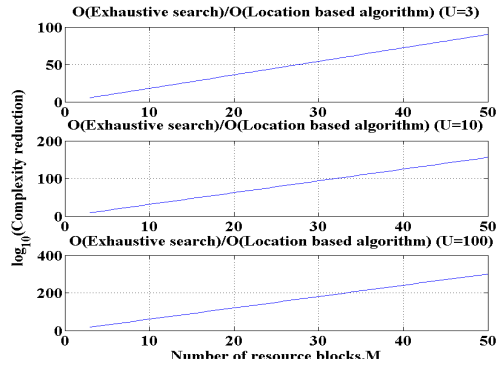


Figure 5-b: Complexity reduction with N=3 and U=3, 10 and 100

computational effort and the complexity of the search of optimum.

Figure 5-a and figure 5-b are the logarithmic curves of complexity reduction (the optimal solution/the location-based algorithm). In figure 5-a, there are three curves varying with U and $M=3, 10$ and 50 respectively. The complexity ratio starts from 5 when $M=3$, 18 when $M=10$ and 91 when $M=50$. From the figure, all three curves go up when U increases. In figure 5-b, there are three curves varying with M and $U=3, 10$ and 100 respectively. The complexity ratio starts from 6 when $U=3$, 10 when $U=10$ and 18 when $U=100$. In this figure, all three curves also go up when M increases. Therefore, from both figures, the proposed location-based algorithm can significantly reduce the complexity of getting the optimal solution especially when the number of users and the number of resource blocks increase.

VI. CONCLUSION

In this paper, a method based on a scheduling matrix to obtain the optimal solution for resource block scheduling in cellular networks has been presented, and the optimal results were obtained for a 3-cell network layout. The optimal cases showed three types of transmission: full cooperation, non-cooperation and 2/3 reuse. Then, a low-complex sub-optimal algorithm using SINR values and user location information to select an optimal scheduling case was proposed. The simulation results showed that this proposed algorithm can achieve nearly 99% of the optimal total network bandwidth efficiency. Moreover, the complexity was significantly reduced by the location-based algorithm compared with the optimal solution. This paper investigated the resource block scheduling in an environment without shadowing effects. The environment with shadowing effects is subject to further work. For the proposed sub-optimal algorithm, user fairness could be considered and the values of distance constraints for different parameter settings could be investigated in future. Further research in a network of more than 3 cells is also of interest.

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